Nepal Agriculture Research Journal
Vol. 15, No. 1, pp. 163-180, 2023
DOI: https://doi.org/10.3126/narj.v15i1.51926

Rice demand and production projections for 2050: Opportunities for achieving self-sufficiency in Nepal

Krishna Prasad Timsina[1*], Devendra Gauchan[2], Samaya Gairhe[3], Sushil Raj Subedi[4], Bhanu Bhakta Pokhrel[3], Santosh Upadhyay[5], Krishna Dev Joshi[6], Sunita Pandey[7] and Jiban Shrestha[8]

[1]National Agricultural Policy Research Centre, Khumaltar, Lalitpur, Nepal
[2]Alliance of Bioversity International and International Centre for Tropical Agriculture, Kathmandu, Nepal
[3]Nepal Agricultural Research Council, Nepal
[4]National Rice Research Program, Dhanusa, Nepal
[5]International Rice Institute (IRRI), Field Office, Directorate of Agricultural Research Lumbini Province, Khajura, Banke, Nepal
[6]International Rice Research Institute (IRRI), Nepal Office, Vegetable Crops Development Centre, Khumaltar, Lalitpur, Nepal
[7]Prime Minister Agriculture Modernization Project (PMAMP), Project Management Unit, Khumaltar, Lalitpur, Nepal
[8]National Plant Breeding and Genetics Research Centre, Khumaltar, Lalitpur, Nepal
[*]Corresponding author's email: krishnatimsina2000@gmail.com
[*]ORCID: https://orcid.org/0000-0003-4005-7039

ARTICLE INFO

Research Paper

Received: September 20, 2022
Revised: January 19, 2023
Accepted: January 29, 2023
Published: February 01, 2023

Contents available at
http://www.sasnepal.org.np

Published by Society of Agricultural Scientists Nepal (SAS-Nepal).

ABSTRACT

Rice is a major food, contributing 67% of cereal consumption in Nepal. It is playing a substantial role in food and nutritional security. Rice production is not sufficient to meet domestic consumption, so its import has been increasing. This study aims to explore whether Nepal can be self-sufficient in rice production in the current context of increasing rice demand and changing climate. We assessed the degree to which Nepal can be self-sufficient in rice production by the years 2030, 2040, and 2050, evaluating 12 different scenarios of demand driven by production, population growth, income, and climate change effect. We used compound growth rate estimation for analyzing the growth of rice production and population growth over time. Auto-regressive regression model was used to analyze the relationship of rice import and demand with domestic production, income, and population. A significant (p=0.000) positive impact of income on the import of rice was estimated, whereas significantly (p=0.000) higher impact of production on demand was estimated compared to income. Based on current rice productivity growth of 1.47% and population growth of 1.3% per year over three decades, the country will not achieve self-sufficiency until 2050.The situation would be further worsened in climate change scenarios. However, integrating the population growth rate of the last decade (0.57% per annum) with two productivity growth rate scenarios (current and (ii) 5% annual increment), the country can be self-sufficient by 2040. Based on different scenarios, the estimated demand can be met by increasing current productivity by at least 27–43% by 2030 and 42–85% by 2050. The study identified major gaps and opportunities in the rice production systems of Nepal and provided evidence-based solutions to meet the future demands in the context of increasing population and income, declining land availability, and high vulnerability to climate change.

Keywords: Climate change, food security, productivity growth, rice, self-sufficiency

Cited as: Timsina KP, D Gauchan, S Gairhe, SR Subedi, BB Pokhrel, S Upadhyay, KD Joshi, S Pandey and J Shrestha. 2023. Rice demand and production projections for 2050: Opportunities for achieving self-sufficiency in Nepal. Nepal Agriculture Research Journal **15**(1): 163-180. DOI: https://doi.org/10.3126/narj.v15i1.51926

INTRODUCTION

Rice (*Oryza sativa* L.) is critical to food and nutrition security (67% of total cereal consumption and 23% of protein intake), employment, and income for farmers in addition to its contribution to the economy in Nepal (Gauchan et al 2022). It contributes about 20% to Agricultural Gross Domestic Product (AGDP) and 7% to Gross Domestic Product (GDP) (MoALD 2020, CBS 2018), being planted in 1.49 million ha with an average productivity of 3.76 mt ha^{-1} in 2019 (MoALD 2019).

With improved road infrastructure, urbanization and higher income mostly due to remittance, more people in the hilly and mountainous regions of Nepal have switched to rice-based diets, thus creating demand including branded fine, aromatic, and long grain rice (CDD 2015). The demand of most of this rice in the market is supplied from India, despite their higher market price (Pudasainee et al 2018). Insufficient production to meet demand of fine quality rice is also contributing to the galloping rice import (Gairhe et al 2020). A recent study by Joshi et al (2020) revealed that coarse and medium rice varieties cover nearly 76% of the total milled rice and the share of medium fine and fine rice varieties were 17% and 7%, respectively. However, the study did not notice even a single case of long and extra-long slender rice varieties being milled in the surveyed area.

Domestic production of rice is not sufficient to meet its growing demand. Therefore, rice import in the country is increasing (Tripathi et al 2018). In order to achieve rice self-sufficiency aggregate production needs to be increased (Giri et al 2017). To promote national food security, gaining self-sufficiency in rice production is indispensable (Bishwajit et al 2013). Tripathi et al (2018) have estimated the demand of rice in Nepal by 2035 but the study did not include some of the dynamic variables in rice production such as changes in the intervention of improved technology and the likely adverse effects of climate change over the longer period of time. Moreover, many past studies lacked both short and long-term strategies and action plans to achieve rice self-sufficiency in the country by developing technology-intensive mission programs in different agro-ecologies, production environments and farming systems.

Rice yield or productivity is a complex phenomenon as it depends on the interaction between genotype (variety), environment, and management. Rice production environments in Nepal are predominantly rainfed, diverse, complex, and stress-prone, where yield fluctuation is common. Available improved technologies, crop management practices and input supply such as access to chemical fertilizer are uncertain and the exposure to climate change (e.g. drought, floods), the natural disasters and market price fluctuation are frequent. Despite these in the budget speech of FY 2021/2022 (section 108, the Government of Nepal) ambitiously aimed to be self-sufficient in rice production in the next five years (MoF 2021). Hence, the objective of this study was to analyze different static and dynamic scenarios of rice production, supply and demand for the next 10, 20 and 30 years considering the challenges and opportunities in rice-based production systems of Nepal. The analysis will provide insights about the likely status of self-sufficiency and offer actions and evidence-based solutions for increasing productivity to meet increasing future rice demands in the context of increasing population and income and high vulnerability to climate change. The study tried to answer the following research questions.

- What is the current status of rice productivity and yield gaps in different rice production environments in Nepal?

- Can Nepal produce enough rice to meet future demand in the current growth rate of rice yield and population (business as usual scenario)?
- What will be the likely situation of rice self-sufficiency in the future under the negative effect of climate change?
- What are the major drivers of domestic demand and import growth of rice in Nepal?
- What will be the level of rice productivity needed to meet self-sufficiency in rice to meet increasing demand by 2030 and 2050?

METHDOLOGY

This paper is developed mainly from the literature review, expert consultations and analysis of secondary data and information from government and other sources. The study analysed yield gap in rice production systems to devise appropriate strategies for closing the yield gap and thereby achieving rice self-sufficiency in Nepal. We used a compound growth rate estimation for analyzing growth of rice production and population growth over time. In addition, production and demand growth of rice and self-sufficiency ratio (SSR) was estimated for the years 2030, 2040 and 2050 in twelve different scenarios combining three rice production scenarios *viz.* (a) at normal current growth rate (b) at 5% increase in current growth rate (c) 10% decrease in current growth rate, and (d) demand scenarios *viz.* (i) at population growth rate of the last 3 decades (1991-2019) (ii) at population growth rate of the last one decade (2009-2019) (iii) at population growth rate of the last 3 decades (1991-2019) with 5% increase in rice demand per annum (iv) at population growth rate of the last one decade (2009-2019) with 5% increase in rice demand per annum. The scenarios details are enlisted in Annex 1, which mainly includes estimated rice production and demands under twelve situations *viz*; (a) P1D1: current constant growth rate of rice (1.47% per annum) and population (1.30% per annum) (b) P1D2: low growth rate of population (0.57% per annum of the latest decade growth rate of 2010-2019) with constant rice growth rate (c) P1D3: current constant growth rate of rice and population with 5%increase in rice demand per annum (d) P1D4: current constant growth rate of rice and low growth rate of population with 5% increase in rice demand per annum (e) P2D1: increased rice production growth rate of 5% per annum after 2025 with constant production and population growth (f) P2D2: low population growth rate with increased rice production growth rate of 5% per annum after 2025 (g) P2D3: increased rice production growth rate of 5% per annum after 2025 with constant production, and population growth with increase in rice demand by 5% per annum (h) P2D4: increased rice production growth rate of 5% per annum after 2025 with constant production, and low population growth with increase in rice demand by 5% per annum (i) P3D1: decreased rice production growth rate of 10% per annum after 2025 due to climate change with constant production and population growth (j) P3D2: low population growth rate with decreased rice production growth rate of 10% per annum after 2025 due to climate change effect (k) P3D3 decreased rice production growth rate of 10% per annum after 2025 with constant production, and population growth with increase in rice demand by 5% per annum (l) P3D4: decreased rice production growth rate of 10 % per annum after 2025 with constant production, and low population growth with increase in rice demand by 5% per annum.

The model (details of dependent and explanatory variables used in the models are given in Table 1) was estimated as an Autoregressive (AR1) regression by the Prais-Winsten method (that involves GLS procedure) to account for the first-order autocorrelation.

$$Y_t = a + X_t\beta + u_t \qquad (1)$$

Y_t = dependent variable at time t, X_t = matrix of explanatory variables, β = vector of coefficients, u_t = error terms, it can be serially correlated over time t, where the errors satisfy

$$u_t = \rho u_{t-1} + e_t \qquad (2)$$

ρ =rho value and the et are independent and identically distributed as N (0, σ).

The seven Models with Durbin-Watson statistics (transformed) close to two were selected to avoid autocorrelation in the sample. Similarly, in each model, model with lower Akaike Information Criterion (AIC) were selected that best fits the data. We had selected the Prais–Winsten over Cochrane–Orcutt method. The Cochrane-Orcutt method involves omitting the first observation in the data, and therefore the sample should be large enough to follow this method (Culas and Timsina 2019). Since a relatively small sample (1990-2019) in this study, the Prais-Winsten method favored over the Cochrane-Orcutt method which may be more appropriate for estimating models with lagged dependent variables. The analysis is focused in the context of existing liberal economic policies (no import restrictions) and open border system that will continue to remain in the future. The major gaps and opportunities in rice based production systems of Nepal to meet the future demands in the context of increasing population and income, declining land availability and high vulnerability to climate change are outlined.

Table 1. Details of dependent and explanatory variables used in different AR1 (Prais-Winsten method) regression

Model 1	Model 2	Model 3	Model 4	Model 6
Dependent variable: Year (1990-2019)	Dependent variable: Year (1990-2019)	Dependent variable: Year (2009-2019)	Dependent variable: Log of rice import (1990-2019)	Dependent variable: log of domestic rice demand (1990-2019)
Log of production	Log of population	Log of population	Log of production	Log of production
			Log of GDP per capita	Log of GDP per capita
			Log Population	Log of population
				Log of Import
				Log domestic rice price

Note: Models 5 and 7 were estimated using only significant variables from the models 4 and 6, respectively, data source: Production data from, MoALD (2020). Other data's (population, import, demand, per capita income, and price) from FAOSTAT (2019).

RESULTS

Analysis of rice yield gap

Rice in Nepal is grown from high potential production domains to extreme marginal environments. These include stress-prone (upland, drought, flood prone) to irrigated less favourable and irrigated favourable production environments. The strategy to transform rice productivity has to integrate these diversities and realities. Major rice production domains/environments are summarized in Table 2.

Table 2. Rice production environment/systems and their importance

Rice Production Environment	**Tentative Area (ha)***	**Attainable Yield (mt ha^{-1})**	**Actual Yield (mt ha^{-1})**	**Yield Gap (mt ha^{-1})**
Upland (Ghaiya), drought prone and shallow bunded rainfed and flood prone	477,600	4.5	2.5	2.0
Irrigated favourable	514,960	8.7	4.0	4.7
Irrigated less favourable	487,440	6.5	3.2	3.3

Source: *Author's estimate, CSISA (2020)

Attainable yield is the crop yield grown under optimal management practices (i.e., recommended plant density, non-limiting nutrient condition, effective control of biotic stresses, etc.) in farmers' fields (Van Ittersum et al 2013). The yield gap was common across all production environments. It is ironic to see that the highest yield gap was found in irrigated favorable rice environments. Even with assured irrigation, farmers are realising less than half of the attainable yield. According to a study, farmers did not have resources to adequately invest in technologies such as quality seed, fertilizers, pesticides, and other inputs as farm labour consumed 73% of the total cost of rice production (PACT 2012). This indicates that rice farmers are not using new high-yielding rice varieties and associated agronomic practices. The analysis is an eye-opener as there is huge potential to improve rice productivity.

In a study jointly implemented by International Rice Research Institute (IRRI) and Nepal Agriculture Research Council (NARC) rice yield of up to 6 mt ha^{-1} was achieved using direct-seeded rice (DSR) method on Sambha Mahasuri -1 rice variety with modest agronomic practices. Net profit of up to NPR 62,000 ($570/ha) with a benefit-cost ratio of 2.0 was obtained in DSR while it was only 1.08 in traditionally transplanted rice (TPR). This was largely possible due to a reduction in the cost of labour (Table 3).

Table 3. Use of farm labour (per ha) in Transplanted rice (TPR) and Direct seeded rice (DSR)

Activities	**Unit**	**TPR**		**DSR**	
		Qty	**Amount**	**Qty**	**Amount**
Labour	Person/day	93.5	37,400	14.5	5,800
Tractor	Hour	10.25	17,300	7.5	19050
Irrigation	Hour	120	12,000	90	9,000

Source: IRRI, NARC unpublished data 2018

Low productivity of rice can be attributed to poor use of major plant nutrients. In comparison to the recommended doses, only 46% of Nitrogen, 66% of Phosphorus and 33% of Potassium were used on rice crop and it is not surprising that huge yield gaps existed in all the production systems.

Growth rates of production and population

The growth rate of edible rice production is the important factor that influences the most in the domestic food availability and meeting food security of the population. Similarly, the population has a direct impact on demand for rice. Average annual population growth rate of

Nepal between 1961 and 2001 was 2.25% which had declined at the average annual growth rate of 1.35% between 2001 and 2011.

Similarly, the total population of Nepal is projected to grow to 30.4 million by 2021 and the average annual growth rate is estimated to be 1.36% (CBS 2014). However, we have estimated population growth rates in two different periods *viz.* over three decades (1990/91-2018/19) to make it consistent with annual growth rate of rice production for the same period, and last decade ((2009/10-2018/19) to consider the latest growth rate of the population while estimating demand. The main purpose of these estimates was to use in demand and supply projection for the coming 30 years to make different (worst and best) scenarios. The details of the growth rate are presented in Table 4.

Table 4. Compound growth rate estimation

Description	Growth rate (% per annum)
Model 1: Edible rice production (1990/91-2018/19)	1.47***
Model 2: Population growth rate (1990/91-2018/19)	1.30***
Model 3: Population growth rate (2009/10-2018/19)	0.57***

Source: Author's estimation, 2021; *** means significant at 1% level of significance

Projection of production and demand of rice

The demand of rice in Nepal has always been higher for last four decades than its domestic production resulting in huge imports and causing too much dependence over different countries, mainly from India. We have estimated production and demand of rice as well as self-sufficiency status for the coming 30 years until 2050 under different scenarios of production and demand change driven by improved technology intervention, adverse impact of climate change and population growth for different periods (2030; 2040; 2050). Difference assumptions are made to create twelve scenarios to estimate supply (production) and demand based on the baseline situation of 2019 (Table 5 and Table 6).

The analysis showed that the demand for edible rice for Nepal is estimated to be 4.270 to 4.818 million metric tons in 2030. This demand is total domestic demand based on both direct household rice consumption demands and indirect demand for seeds and liquor production etc. This estimate is similar to that of Prasad et al (2011), who projected a need of 4.518 to 4.856 million metric tons of edible rice by 2030 based on pessimistic and optimistic scenarios. Moreover, it is expected that the demand of edible rice for Nepal is estimated to be 4.784 to 6.238 million metric tons by 2050.

Table 5. Estimated production and demand of milled rice by 2050 in different scenarios (1000 mt)

	2019/20			2029/30			2039/40			2049/50		
Scenarios	**Production**	**Demand**	**Surplus/Deficit**	**Production**	**Demand**	**Surplus/Deficit**	**Production**	**Demand**	**Surplus/Deficit**	**Production**	**Demand**	**Surplus/Deficit**
P1D1	3366	4034	-668	3895	4590	-695	4507	5223	-716	5215	5943	-728
P1D2	3366	4034	-668	3895	4270	-375	4507	4519	-13	5215	4784	431
P1D3	3366	4034	-668	3895	4818	-923	4507	5482	-975	5215	6238	-1023
P1D4	3366	4034	-668	3895	4482	-587	4507	4744	-237	5215	5021	194
P2D1	3366	4034	-668	3908	4590	-682	4554	5223	-669	5306	5943	-637
P2D2	3366	4034	-668	3908	4270	-361	4554	4519	34	5306	4784	522
P2D3	3366	4034	-668	3908	4818	-910	4554	5482	-928	5306	6238	-932
P2D4	3366	4034	-668	3908	4482	-573	4554	4744	-190	5306	5021	284
P3D1	3366	4034	-668	3868	4590	-722	4414	5223	-808	5038	5943	-905
P3D2	3366	4034	-668	3868	4270	-402	4414	4519	-105	5038	4784	254
P3D3	3366	4034	-668	3868	4818	-950	4414	5482	-1068	5038	6238	-1200
P3D4	3366	4034	-668	3868	4482	-614	4414	4744	-329	5038	5021	17

Source: Author's estimation, 2021. Details of scenarios (P1D1 to P3 D4) are given in Annex 1.

Table 6. Estimated Self-sufficiency Ratio (SRR) of rice based on static and dynamic scenarios

Static scenarios							**Dynamic scenarios**					
	P1D1	**P1D2**	**P1D3**	**P1D4**	**P2D1**	**P2D2**	**P2D3**	**P2D4**	**P3D1**	**P3D2**	**P3D3**	**P3D4**
2019/20	83	83	83	83	83	83	83	83	83	83	83	83
2029/30	85	91	81	87	85	92	81	87	84	91	80	86
2039/40	86	100	82	95	87	101	83	96	85	98	81	93
2049/50	88	109	84	104	89	111	85	106	85	105	81	100

*Source:*Author's estimation, 2021

Analysis revealed that the country cannot achieve self-sufficiency until 2050 under the current rice productivity growth of 1.47% and population growth rate of 1.3% per annum over three decades. The situation would be aggravated in case of adverse impacts of climate change scenarios. However, by integrating the population growth rate of the last decade (0.57% per annum) in the model with two productivity growth rate scenarios (a) current and (b) 5% annual increment, the country can be self-sufficient by 2040. Presently the self-sufficiency ratio of rice is 83% indicating that 17% of the production is met through imports (Table 6). While projecting production (supply), we assumed that our productivity will be increased by at least 15-17% by 2030 and 49-58% by 2050. To achieve this productivity, we need to increase the coverage of 10 % of the current area of hybrid rice production to 20% by 2030 with average productivity of at least 6 mt ha^{-1}, and 30% area by 2050 with productivity ranges from 6.5-7.0 mt ha^{-1}. Similarly, coverage of improved inbred varieties should be maintained above 60% with average productivity of 4 mt ha^{-1} by 2030 and 5.0-5.5 mt ha^{-1} by 2050 (Table 7). The current coverage of hybrid rice is estimated based on imported rice seeds in Nepal. In 2019, 55 (49 hybrids and 6 inbreds) imported rice seed varieties are on the active lists. Among them, 27 Indian and 3 Chinese seed companies are selling those rice varieties through 16 local traders who imported 2780 mt rice seed in 2019 (SQCC 2020).

We assumed that the current rice area will not decline, as the agriculture area converted to non-agriculture purposes will be compensated by increasing *Chaite* (Spring) rice area. Yadav (2020) recommended increasing spring rice (*Chaite)* area to 330 thousand ha by 2025 from 120 thousand ha at present. However, increasing *Chaite* rice area by nearly 3 fold would depend on many factors including competitiveness and profitability of *Chaite* rice with other competing crops, development of year-round irrigation system, choice of appropriate *Chaite* rice varieties to fit into the narrow window of cropping sequences. This is doable given that rice is developed into a fully mechanized production system supported by rice nursery enterprises. Another option to increase rice production and productivity in Nepal is the development and adoption of hybrid rice technology. The experience from other Asian countries outside China revealed that hybrid rice area comprises a small proportion (1-7%) of the total rice area in each country (FAORAP and APSA 2014). This experience can be a useful guideline while developing hybrid rice technology in Nepal. Therefore, we have set the maximum limit of up to 25% by 2030 and 30% by 2050.

Table 7. Needed rice yield increment to meet estimated production by 2050 at different scenarios

Description	Different scenarios								
	Normal growth rate@1.47 % per annum			**5% increase in growth rate after 2025 (1.54% per annum)**			**Decrease in 10% growth rate after 2025 (1.33% per annum)**		
Base productivity- 2019 (mt ha^{-1})	3.59			3.59			3.59		
Estimated productivity -2030 (mt ha^{-1})	4.15			4.17			4.13		
Estimated productivity-2050 (mt ha^{-1})	5.56			5.66			5.37		
Required % change in yield 2030 (reference to base year)	15.71			16.11			14.92		
Precondition to achieve required yield in 2030	Hybrid A=20%, Y=6 t/ha	Inbred varieties A=64%, Y=4.0 t/ha	Local A=16 %, Y=2.5 t/ha	Hybrid A=20 % Y=6 t/ha	Inbred varieties A=65%, Y=4.0 t/ha	Local A=15%, Y=2.5 t/ha	Hybrid A=20 %, Y=6 t/ha	Inbred varieties A=62 %, Y=4.0 t/ha	Local A=18 % Y=2.5 t/ha
Required % change in yield 2050 (reference to base year)	54.93			57.62			49.67		
Precondition to achieve required yield in 2050	Hybrid A=30 %, Y=6.7 t/ha	Inbred varieties A=60 %, Y=5.5 t/ha	Local A=10 %, Y=2.5 t/ha	Hybrid A=30 % Y=7 t/ha	Inbred varieties A=60 %, Y=5.5 t/ha	Local A=10 %, Y=2.5 t/ha	Hybrid A=30 %, Y=6.5 t/ha	Inbred varieties A=60 %, Y=5.2 t/ha	Local A=10 % Y=2.5 t/ha

Note: A= area, Y=yield; conversion factor used from paddy to rice is 0.60

Moreover, based on different scenarios, the estimated rice demand can be met through increasing current productivity by at least 27-43% by 2030 and 42-85% by 2050. To achieve this demand, we need to increase the coverage of 10 % of current area of hybrid production to 25% by 2030 with average productivity of at least 6.5 mt ha^{-1}, and 30% area by 2050 with productivity ranges from 6.5-8 mt ha^{-1}. Similarly, coverage of inbred varieties should be maintained above 60% with average productivity of 4.1-5 mt ha^{-1} by 2030 and 4.8-6.5 mt ha^{-1} by 2050 (Table 8).

Even though there is increased production and productivity of rice over the last 3 decades , high import dependency of rice poses high risks of vulnerability of the country in food security during major economic crisis such as financial and food crisis of 2007-08, where major food exporting countries such as India restricted to supply food to neighboring countries including Nepal. Therefore, we have analyzed the Autoregressive regression model (Model 4 in Table 9) to find out the drivers of rice imports in Nepal. Results indicated that the increase in per capita income is the major driver of increasing rice imports in Nepal. Increase in population and domestic rice production has positive and negative relationship, respectively with import but both are insignificant. If we increase rice domestic production by 1%, the import will be reduced by 1.39 %. It shows that, if we increase domestic production without considering consumer preference, the achievement of targeted import substitution will not be possible. We further analyzed model 5 using only significant variables from model 4 and found more robust results. It showed that 1 % increase in per capita income, rice import will be increased by 2.55%.

Similarly, we have analyzed another Autoregressive regression model (Model 6 in Table 9) to find out the drivers of domestic rice demand in Nepal. Results revealed domestic production, import and per capita income were the major factors to determine the domestic rice demand whereas population growth and price are found non-significant. We further analyzed model 7 using only significant variables from model 6 and found more robust results. Results showed 1% increase in domestic production, per capita income and import, the domestic demand increased by 1.45 , 0.070 and 0.012%, respectively. The effect of domestic production to domestic demand of rice is found higher.

Table 8. Needed rice yield increment to meet projected demand by 2050 at different scenarios

Description	**Different scenarios**											
	@1.30 population growth and 141 kg/ person/annum			**@0.57 population growth and 141 kg/ person/annum**			**@1.30 population growth and 148 kg/person/annum after 2021**			**@0.57 population growth and 148 kg/ person/annum after 2021**		
Base productivity-2019 (mt ha^{-1})	3.59			3.59			3.59			3.59		
Estimated productivity to meet demand in 2030 (mt ha^{-1})	4.90			4.55			5.14			4.78		
Estimated productivity to meet demand in 2050 (mt ha^{-1})	6.34			5.10			6.65			5.36		
Required % change in yield to meet demand in 2030 (reference to base year)	36.36			26.85			43.13			33.15		
Precondition to meet demand in 2030	Hybrid	Inbred varieties	Local	Hybrid	Inbred varieties	Local	Hybrid	Inbred varieties	Local	Hybrid	Inbred varieties	Local
	A=25%, Y=6.5 t/ha	A=65%, Y=4.65t/ha	A=10 %, Y=2.5t/ha	A=25 %, Y=6.5t/ha	A=65%, Y=4.1t/ha	A=10 %, Y=2.5t/ha	A=25 %, Y=6.5t/ha	A=65%, Y=5t/ha	A=10%, Y=2.6t/ha	A=25 %, Y=6.5t/ha	A=65 %, Y=4.5t/ha	A=10 %, Y=2.5t/ha
Required % change in yield to meet demand in 2050 (reference to base year)	76.56			42.12			85.32			49.18		
Precondition to meet demand in 2050	Hybrid	Inbred varieties	Local	Hybrid	Inbred varieties	Local	Hybrid	Inbred varieties	Local	Hybrid	Inbred varieties	Local
	A=30% Y=8 t/ha	A=60% Y=6t/ha	A=10 % Y=3.5t/ha	A=30 % Y=6.5t/ha	A=60 % Y=4.8t/ha	A=10 % Y=2.7t/ha	A=30 % Y=8t/ha	A=60% Y=6.5t/ha	A=10% Y=3.5t/ha	A=30 % Y=6.5t/ha	A=60% Y=5.2t/ha	A=10 % Y=3t/ha

Note: A= area, Y=yield; conversion factor used from paddy to rice is 0.60

Table 9. Estimated drivers of import and demand of rice in Nepal

Description	Model 4 Dependent variable= Import	Model 5 Dependent variable= Import	Mode 6 Dependent variable= domestic demand	Model 7 Dependent variable= domestic demand
Production	-1.39 (1.80)		1.384 (0.098)***	1.459 (0.04)***
GDP per capita	2.52 (0.75)**	2.55 (0.40)***	0.107(0.05)**	0.07(0.00)**
Population	0.32 (0.42)		0.009(0.04)	
Import			0.017 (0.00)**	0.012 (0.00)**
Domestic rice price			-0.036 (0.54)	
F(2, 31) Value	14***	39.5***	231***	1074***
R-squared	0.39	0.37	0.99	0.99
Rho	0.59	0.61	0.57	0.64
DW statistics (transformed)	1.69	1.62	1.85	1.77
AIC value	88	84	-101	-151

*** and ** denotes significance at 1 and 5 % level of significance, respectively; figure in parentheses indicates semi robust standard error. Model 5 and 7 include significant variables only from model 4 and 6, respectively.

DISCUSSION

Earlier studies suggested the predominance of old and obsolete rice varieties in Nepal (Witcomb et al 2016 a, b, Gauchan and Pandey 2012). This is one of the major reasons for low rice productivity and the high yield gap. Joshi et al (2012) highlighted the importance of accelerating variety testing, release, and adoption to deliver genetic gains from new varieties rapidly. A paradigm shift in fast delivery of genetic gains to farmers' fields is to focus on the varietal replacement (replacing old and obsolete crop varieties by new high yielding multi stress-tolerant ones) over merely replacing seeds of a variety irrespective of cultivar age (Joshi et al 2016). Similarly, the study by Timsina et al (2018) highlighted the need to focus on promoting new varieties before its release.

Earlier studies (Timsina et al 2022) have shown that the estimated demand can be met through increasing current productivity by at least 27-43% by 2030 and 42-85% by 2050 based on different scenarios. To achieve this productivity is not an easy task with current infrastructure in Nepal. It is important to emphasize that productivity drivers vary by geography irrigation intensity, rainfall, nitrogen and phosphorus fertilizers (Devkota et al 2021). Tripathi et al (2018) reported that the yield of rice needs to be raised from the current 3.0 mt $ha^{-1}$to 6.0-7.0 mt ha^{-1} by 2035 assuming that the current rice production area. However, they did not disaggregate rice varieties based on the area and productivity.

Devkota et al (2021) reported that the 1.86 mt ha^{-1} gain in rice yield would be possible through the adoption of good agronomic practices. The yield gaps varied across the six terai districts of Nepal ranges from 35 to 45% which can be reduced through adopting six-component technologies: healthy seedlings, use of high-yielding hybrid or modern rice varieties, timely planting, recommended fertilizer rates, supplemental irrigation, and timely weed management.

Rice productivity is low in Nepal as compared to global average productivity of 4.0 mt ha^{-1} due to poor investment in research, technological development (Gauchan and Pandey 2011), mismatch in resource allocation (Shrestha and Gairhe 2016) and inadequate inputs and management practices (Gairhe et al 2018, Timsina et al 2012). In support of these ideas, several studies reported that farmers have been applying lower fertilizer rates than recommended which caused higher yield gaps (Timsina et al 2021, Devkota et al 2021). The reasons for using low fertilizers doses in most cases in recent years are related to unavailability, if available then high prices of informally traded fertilizers, and investment aversion due to production risks from drought and flood (Devkota et al 2021).

The estimated demand can be met through increasing current productivity by at least 27-43% by 2030 and 42-85% by 2050. For this, different intensive programs should be designed and support should be provided to increase the coverage of 10 % of the current area of hybrid production to 25% by 2030 by increasing area under spring rice (*Chaite* rice) and bringing stress-prone areas under this technology with average productivity of at least 6.5 mt ha^{-1}, and 30% area by 2050 with productivity ranges from 6.5-8 mt ha^{-1}. Similarly, coverage of improved inbred varieties should be maintained above 60% with average productivity of 4.1-5 mt ha^{-1} by 2030 and 4.8-6.5 mt ha^{-1} by 2050. Nepal needs a clear road map to transform the rice system by sustainably intensifying the production of inbred varieties, hybrids and local landraces in different production environments based on their suitability and potentiality. Improvement in value chains of rice by improving linkages of producers and entrepreneurs (rice millers and traders) and promoting market diversification towards locally produced specialty and fine rice varieties and products to meet consumer demand might be a complementary strategy to meet future demands.

Any one category of rice varieties alone is less likely to achieve these highly ambitious targets. Early generation seed multiplication for wider dissemination and farm level adoption of newly released high yielding climate resilient rice varieties are vital to reduce adoption lag phases and using NE-based nutrient management strategy in combination with adoption of other good resilient agronomic practices will ensure high productivity gains by reducing yield gaps at the farm level.

The consumption pattern of rice has changed from consuming coarse and medium to fine and aromatic rice in the present day (Dhungel and Acharya 2017). The consumption of fine rice is increasing and the opposite was found in coarse rice. The import of rice can be substituted through increasing productivity with the increased use of fine and aromatic high-yielding hybrids (Gairhe et al 2021). The present study indicated that increased demand of rice triggered in recent years due to (i) rise in income growth (mainly due to remittances) that pushed also the demand for fine and aromatic rice (ii) improvement in road connectivity leading to a drastic increase in rice consumption in the hills and mountainous areas (Tripathi et al 2018). Gairhe et al (2021) indicated that rice import in Nepal comprising mainly of fine and aromatic rice, in general.

To be self-sufficient in rice production in Nepal, to a great extent, increasing productivity that supports higher milling recovery of rice grains might be a complementary strategy. Yadav (2020) reported that the milling recovery %age in Nepal can be increased up to 72% from the current average of 60% level. Productivity and profitability of rice can be increased with use of farm machinery, which reduces not only cost of production but also improves efficiency in production. Acharya et al (2021) showed that rice farmers using farm machinery are technically more efficient than those who do not use.

CONCLUSION

Rice is the most important food crop for ensuring food and nutritional security in Nepal. Despite its importance and improvement in yield over time, the current rice yield level is low with high yield gaps. The country is importing rice in an increasing trend which is mainly influenced by increased per capita income, insufficient domestic production in comparison to the population growth and preference of fine rice. The present trends of demand and supply of rice, in general revealed that it would be difficult to achieve to attain the self-sufficiency of rice production in Nepal at least until the year 2050 under the current rice productivity growth of 1.47% and population growth rate of 1.3% per annum. The future situations might be aggravated more in case of adverse impacts of climate change scenarios. There could be resilience on demand and improve self-sufficiency in rice through the adoption of improved technologies and intensification - of rice farming such as improved high yielding inbred and hybrid rice varieties, and other climate resilient technologies and increase area coverage towards spring (Chaite) irrigated rice, good agronomical practices, mechanization, efficiency in milling recovery, reducing post-harvest losses, implementation of minimum support price for food storage, transportation and public distribution system jointly by provincial and federal governments. This improved adoption of technologies and management practices by farmers and an enabling environment, created from public sectors might encourage the rice farmers to invest more in the future to increase productivity and improve efficiency in milling and marketing. The prerequisite to working towards putting in place a self-sufficient rice system in Nepal is to develop a critical mass of rice scientists trained on advanced technologies, upgrading research infrastructures and transformation of agricultural extension to cater for the emerging needs of the beneficiaries of the rice system. This will require a significant increase in the investment on agriculture research and development, irrigation and market infrastructures, input supply, value chain development and better linkage among research, extension and education system. Policies and institutional support services for input and output markets targeting sustainable intensification of rice farming across different production environments are equally important.

Authors' Contributions

KPT, DG and SG were involved in conceptualizing, designing, data analysis and drafting of the research paper. SRS, BBP, SU, KDJ, SP and JS were responsible for the literature review and provided critical feedback on the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Publisher's Note

All claims made in this article are those of the authors alone; they do not necessarily reflect the views of any affiliated organizations, the publisher, the editors, or the reviewers.

REFERENCES

Acharya P, PP Regmi, D Gauchan, DB KC and GB KC. 2021. Comparative study on technical efficiency of mechanized and traditional rice farm in Nepal. Journal of Agriculture and Natural Resources **3**(2): 82-91.

Bishwajit G, S Sarker, MA Kpoghomou, H Gao, L Jun, D Yin and S Ghosh. 2013. Self-sufficiency in rice and food security: a South Asian perspective. Agric & Food Secur. 2: 10. https://doi.org/10.1186/2048-7010-2-10

CBS. 2014. Population Monograph of Nepal, Volume I, Population Dynamics. Kathmandu: Central Bureau of Statistics.

CBS. 2018. National Economic Census 2018: A New Initiative in the National Statistical System of Nepal. Central Bureau of Statistics.

CDD. 2015. Rice Varietal Mapping in Nepal: Implications for Development and Adoption. Crop Development Directorate, Department of Agriculture, HariharBhawan.

CSISA. 2017. Annual Report, Cereal Systems Initiatives for South Asia (CSISA). http://csisa.org/wp-content/uploads/sites/2/2014/06/CSISA-Phase-III-Annual-Report-2016.pdf.

Culas R and KP Timsina. 2019. Land use and profitability in wheat production: Australian wheat sheep zone. International Journal of Food and Agricultural Economics **7**(2):107-126.

Devkota KP, M Devkota, GP Paudel and AJ McDonald. 2021. Coupling landscape-scale diagnostics surveys, on-farm experiments, and simulation to identify entry points for sustainably closing rice yield gaps in Nepal. Agricultural System; **pp.** 192

Dhungel S and P Acharya. 2017. Role of rice in food and nutrition security in Nepal. **In:** Rice Science and Technology in Nepal (MN Poudel, DR Bhandari, MP Khanal, BK Joshi, P Acharya and KH Ghimire, eds) Crop Development Directorate (CCD), Hariharbhawan and Agronomy Society of Nepal (ASoN) Khumaltar; **pp**.77-85.

FAORAP and APSA. 2014. Hybrid rice development in Asia: Assessment of limitations and potential. Proceedings of the Regional Expert Consultation on “Hybrid Rice Development in Asia: Assessment of Limitations and Potential”, 2-3 July 2014, Bangkok, Thailand: FAO Regional Office for Asia and the Pacific and Asia-Pacific Seed Association.

FAOSTAT. 2019. Food and Agriculture data. https://www.fao.org/faostat/en/#home

Gairhe S, D Gauchan and K Timsina. 2021. Temporal dynamics of rice production and import in Nepal. Journal of Nepal Agricultural Research Council **7**(1): 97-108. https://doi.org/10.3126/jnarc.v7i1.36932

Gairhe S, H Shrestha and K Timsina. 2018. Dynamics of major cereals productivity in Nepal. Journal of Nepal Agricultural Research Council **4**(1): 60-71. https://doi.org/10.3126/jnarc.v4i1.19691

Gairhe S, RB Yadaw and K Timsina. 2020. Status of rice after NARC establishment in Nepal. **In**: Proceedings of 29th National Summer Crops Workshop (Bhandari D, HK Upreti, R Shrestha, J Tripati, HK Shrestha, KK Mishra, BK Joshi, AR Ansari, BP Tripathi, S Baidya, J Shrestha, M Tripati, P Paneru eds), held on 17-18 June, 2018 at Regional Agricultural Research Station (RARS), Lumle, Kaski, Nepal. Nepal Agricultural Research Council; **pp**.519-531.

Gauchan D and S Pandey. 2011. Is investment in rice research in Nepal adequate and balanced across production environments? Some empirical evidence. Q. J. Int. Agric. **50**(4): 305-324.

Gauchan D and S Pandey. 2012. Synthesis of key results and implications. In Patterns of Adoption of Improved Rice Varieties and Farm-level Impacts in Stress-Prone Rainfed Areas in South Asia, 1–18 (Eds S Pandey, D Gauchan, M Malabayabas, M Bool-Emerick and B Hardy). Los Baños, Philippines: International Rice Research Institute.

Gauchan D, KP Timsina, S Gairhe, J Timsina and KD Joshi. 2022. Cereal Demand and Production Projections for 2050: Opportunities for Achieving Food Self-Sufficiency in Nepal. **In:** Timsina J, TN Maraseni, D Gauchan, J Adhikari, H Ojha, (eds) Agriculture, Natural Resources and Food Security. Sustainable Development Goals Series. Springer, Cham. https://doi.org/10.1007/978-3-031-09555-9_2

Giri A, R Giri, V Nelson, K Lovercamp, S Sharma and I Protopop. 2017. Can Nepal Attain Self-Sufficiency in Major Crops Production? Journal of Forest and Livelihood **15**(2): 1-12.

Joshi KD, AQ Rehman, G Ullah, A Baloch, M Hussain, J Ahmad, M Ishaq, G Ahmad, N Ahmad, SH Abbas, M Qamar, M Ahmad, A Dar, B Khokhar, M Sajid, A Hussain and M Imtiaz. 2016. Yield and Profit from New and Old Wheat Varieties Using Certified and Farmer-Saved Seeds. Journal of Agricultural Science and Technology B **6**:141-151. 10.17265/2161-6264/2016.03.001

Joshi KD, S Upadhyay, P Chaudhary, S Shrestha, K Bhattarai and BP Tripathi. 2020. The Rice Processing Industry in Nepal: Constraints and Opportunities. Agricultural Sciences **11**:1060-1080. https://www.scirp.org/journal/as

MoALD. 2019. Statistical Information on Nepalese Agriculture 2074-75. Ministry of Agriculture and Livestock Development, Government of Nepal.

MoALD. 2020. Statistical Information on Nepalese Agriculture 2075-76. Ministry of Agriculture and Livestock Development, Government of Nepal.

MoF. 2021. Budget Speech of 2021/2022 (2078/79) with Income and Expenditure for Public Sharing. Ministry of Finance (MoF), Singhdarbar, Kathmandu, Nepal.

PACT. 2012. Value Chain Development Plan for Cereal Seed. Project on Agricultural Commercialization and Trade, Ministry of Agricultural Development, Kathmandu, Nepal.

Prasad SK, H Pullabhotla and A Ganesh-Kumar. 2011. Supply and Demand for Cereals in Nepal, 2010-2030. IFPRI Discussion Paper 01120. Environment and Production Technology Division, International Food Policy Research Institute, Washington, D.C. USA.

Pudasainee A, TR Chaulagai, YN Ghimire and BP Chaulagain. 2018. Drivers of transition from export to import of rice in Nepal. Nepalese J. Agric. Sci.**17**: 208-216.

Shrestha HK and S Gairhe. 2016. Is investment in maize research balanced and justified? An empirical study. Journal of Nepal Agricultural Research Council **2**:27-32. https://doi.org/10.3126/jnarc.v2i0.16118

SQCC. 2020. Annual Progress report. Seed quality Control Central, Hariharbawan, Lalitpur

Timsina J, S Dutta, KP Devkota, S Chakraborty, RK Neupane, S Bishta, LP Amgain, VK Singh, S Islam and K Majumdar. 2021. Improved nutrient management in cereals using Nutrient Expert and machine learning tools: Productivity, profitability and nutrient use efficiency. Agricultural System; **pp.** 192

Timsina KP, D Gauchan, S Gairhe, SR Subedi, BB Pokhrel, S Upadhyay and KD Joshi. 2022. Can Nepal be self-sufficient in riceproduction to meet future demand? National Agricultural Policy Research Centre, Khumaltar, Lalitpur.

Timsina KP, KP Shrestha and S Pandey. 2012. Factors affecting adoption of new modern varieties of Rice in eastern Terai of Nepal. **In:** Proceeding of 4th Society of Agricultural Scientist-Nepal (SAS-N) conference held on 4-6 April, 2012 at Lalitpur. Nepal Agricultural Research Council (NARC) and Society of Agricultural Scientists (SAS-N), Nepal; **pp.**48-54.

Timsina KP, YN Ghimire, D Gauchan, S Subedi and SP Adhikari. 2018. Lessons for Promotion of New Agricultural Technology: A Case of Vijay Wheat Variety in Nepal. Agriculture and Food Security **7**: 63.

Tripathi BP, HN Bhandari and JK Ladda. 2018. Rice Strategy for Nepal. Acta Sci. Agric. **2**(9): 171-180.

Van Ittersum MK, KG Cassman, P Grassini, G Wolf, P Tittonell and Z Hochman. 2013. Yield gap analysis with local to global relevance: a review. Field Crop Res. **143**:4–17. 10.1016/j.fcr.2012.09.009

Witcombe JR, K Khadka, RR Puri, NP Khanal, A Sapkota and KD Joshi. 2016a. Adoption of Rice Varieties-I. Age of Varieties and Patterns of Variability. Experimental Agriculture **53**: 512-527. https://doi.org/10.1017/S0014479716000545

Witcombe JR, K Khadka, RR Puri, NP Khanal, A Sapkota and KD Joshi. 2016b. Adoption of rice varieties-II. Accelerating uptake. Experimental Agriculture **53**: 627-643. https://doi.org/10.1017/S0014479716000624

Yadav RB. 2020. Development, challenges and opportunities of rice in Nepal. Paper presented at Nepal Agricultural Research Council (NARC), Singhdurbar Plaza, Kathmandu, Nepal.

ANNEXES

Annex 1. Details of scenarios

1.P1D1	use growth rate of edible rice production (@1.47 per annum) and estimate demand using population growth @ 1.30 per annum over three decades (1990-2019) and assume each person consume @ 141 kg per annum (137.5 direct demand and 3.5 kg indirect demand - i.e for seed, and hh non-food (liquor)
2. P1D2	use growth rate of edible rice production (@1.47 per annum) and estimate demand using population growth @0.57 per annum over a decade(2010-2019) and assume each person consume @ 141 kg per annum (137.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)
3. P1D3	use growth rate of edible production (@1.47per annum) and estimate demand using population growth @1.30 per annum over three decades (2010-2019) and assume each person consume @ 148 kg per annum (@5% increase in demand-144.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)
4. P1D4	use growth rate of edible rice production (@1.47per annum) and estimate demand using population growth @0.57 per annum over a decade (2010-2019) and assume each person consume @ 148 kg per annum (@5% increase in demand-144.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)
5. P2D1	use 1.54 growth rate of edible rice production per annum (increase by 5% on current growth rate @1.47 per annum due to improved technology after 2025) and estimate demand using population growth @ 1.30 per annum over three decades (1990-2019) and assume each person consume @ 141 kg per annum (137.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)
6. P2D2	use 1.54 growth rate of edible rice production per annum (increase by 5% on current growth rate @1.47 per annum due to improved technology after 2025) and estimate demand using population growth @0.57 per annum over a decade(2010-2019) and assume each person consume @ 141 kg per annum (137.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)
7. P2D3	use 1.54 growth rate of edible rice production per annum (increase by 5% on current growth rate @1.47 per annum due to improved technology after 2025) and estimate demand using population growth @1.30 per annum over three decades (2010-2019) and assume each person consume @ 148 kg per annum (@5% increase in demand-144.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)
8. P2D4	use 1.54 growth rate of rice production per annum (increase by 5% on current growth rate @1.47 per annum due to improved technology after 2025) and estimate demand using population growth @0.57 per annum over a decade (2010-2019) and assume each person consume @ 148 kg per annum (@5% increase in demand-144.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)
9. P3D1	use 1.33 growth rate of edible rice production per annum (decrease by 10% on current growth rate @1.47 per annum due to adverse impact of climate change after 2025) and estimate demand using population growth @ 1.30 per annum over three decades (1990-2019) and assume each person consume @ 141 kg per annum (137.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)
10. P3D2	use 1.33 growth rate of edible rice production per annum (decrease by 10% on current growth rate @1.47 per annum due to adverse impact of climate change after 2025) and estimate demand using population growth @0.57 per annum over a decade (2010-2019) and assume each person consume @ 141 kg per annum (137.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)
11. P3D3	use 1.33 growth rate of edible rice production per annum (decrease by 10% on current growth rate @1.47 per annum due to adverse impact of climate change after 2025) and estimate demand using population growth @1.30 per annum over three decades (2010-2019) and assume each person consume @ 148 kg per annum (@5% increase in demand-144.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)
12. P3D4	use 1.33 growth rate of production per annum (decrease 10% on current growth rate @1.47 per annum due to adverse impact of climate change after 2025) and estimate demand using population growth @0.57 per annum over a decade (2010-2019) and assume each person consume @ 148 kg per annum (@5% increase in demand-144.5 direct demand and 3.5 kg indirect demand i.e for seed, and hh non-food (liquor)